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OPERATIONAL RISK MANAGEMENT OF FATIGUE EFFECTS II

James C. Miller
Douglas R. Eddy

NTI, Incorporated
1 ½ South Central Ave
Fairborn, OH 45324

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Air Force Research Laboratory
711 Human Performance Wing
Human Effectiveness Directorate
Biosciences and Protection Division
Biobehavioral Performance Branch
Brooks City-Base, TX 78235

NOTICE AND SIGNATURE PAGE

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Work Unit Monitor
Biobehavioral Performance Branch

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MARK M. HOFFMAN
Deputy Division Chief
Biosciences and Protection Division
Human Effectiveness Directorate
711 Human Performance Wing
Air Force Research Laboratory

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This report describes our second attempt to use a quantitative, applied model of fatigue and well-accepted fatigue countermeasures in the context of operational risk management (ORM). The report discusses ORM in terms of the identification of fatigue hazards, assessment of fatigue risks, analysis of fatigue-risk control measures, possible fatigue-risk control decisions, implementation of fatigue risk controls, and the supervision and review of the fatigue ORM process. It builds upon and extends a previous fatigue ORM effort (2005) by combining the occurrence of five specific fatigue indicators with fatigue model predictions of cognitive performance effectiveness (PE). The five indicators were the amount of sleep in the last 24 hours, the cumulative sleep debt, the number of hours awake since the last major sleep period, time of day, and the amount of jet lag or shift lag. In the standard Air Force ORM method, the risk associated with a potential mishap is measured in terms of the probability that a mishap will occur and the potential severity of that mishap. The Fatigue-Performance Assessment System software should automate this process in such a manner as to augment other, required AF ORM documents.

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PREFACE

This report covers the project period of March 30, 2006 to July 29, 2008. The work was performed under Contract Number FA8650-06-C-6606. The program managers were Lts Andrea M. Pinchak and Andrew J. Workman, Biosciences and Protection Division, Air Force Research Laboratory, Brooks-City Base.

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OPERATIONAL RISK MANAGEMENT OF FATIGUE EFFECTS II

INTRODUCTION

This Technical Report (TR) is provided for commanders, safety personnel, aerospace physiologists, schedulers, and others who help to assure the safe completion of Air Force missions that require sustained operations, night operations and irregular schedules. The TR describes our second attempt to use a quantitative, applied model of fatigue and well-accepted fatigue countermeasures in the context of operational risk management. The background and other, relevant material from the first attempt (Miller, 2005b) has been included in this report and modified as needed.

FATIGUE

Fatigue played a role in at least 143 USAF Class A mishaps from FY1972-FY2000 (Luna, 2003). Fatigue was cited as a major or causal factor in 26 USAF Class A mishaps over that same period and cost the Air Force an average of $54 million per year. From FY1990-FY2000, the most frequently cited component of fatigue was "circadian rhythm desynchrony" (cited 69 times), and "physical fatigue" was most often cited as having played the most significant role (21 times).

There are inherent, unavoidable, daily rhythms in human cognitive and physical performance (Appendix A). These rhythms cycle between their high point late in the day to their low point in the pre-dawn hours. Additionally, the state of wakefulness, itself, unavoidably induces the state of sleepiness. If sleep is not acquired, it induces involuntary, unplanned sleep (i.e., falling asleep on the job and at the wheel). As individuals work across the day and night, these rhythms and the states of wakefulness and sleepiness have direct effects upon cognitive and physical performance effectiveness.

Fatigue is a ubiquitous and pervasive problem. It is an enemy we always face when we deploy, when we fight and when we train. Fatigue in its many forms is often misrepresented as an unavoidable risk in military operations, and its severity is often underestimated by those affected.

Each commander, supervisor and operator has a moral responsibility to protect our personnel from the possibility of fatigue-induced mishaps. The work we do with military systems can be hazardous enough, especially when we push the limits of the engineering envelope of a system. As long ago as 1796, Napoleon Bonaparte advised his subordinate commanders that they "must not needlessly fatigue the troops." Today, we have a quantitative, predictive, applied model that allows systematic considerations of fatigue-induced risks. These predictions may be applied to everyday operations through the process of operational risk management.

Fatigue is an abstract term that describes an internal state of a human operator. It takes many forms and in different degrees, both across people and within the same person at different times. For the purposes of this discussion, the types of fatigue were partitioned as follows[1].

- PHYSICAL FATIGUE is a factor when the individual's diminished physical capability is due to overexertion (time or relative load) and it degrades task performance. [The effects of prolonged physical activity, or the effects of brief but relatively extreme physical activity, either of which taxes a person's physical endurance or strength beyond the individual's normal limits.]
- The CIRCADIAN RHYTHM is a factor when the individual's normal, 24-hour, rhythmic biological cycle degrades task performance. This is caused by one or more nights of work or rapid movement (faster than one time zone per day) across more than 3 time zones. These effects are referred to as "shift lag" and "jet lag," respectively. [Continuous time spent in the new time zone will lead to acclimation, but more acclimation time is needed for more time zones crossed. Acclimation to night work may never occur.]
- ACUTE MENTAL FATIGUE is a factor when the individual's diminished mental capability is due to prolonged wakefulness, usually more than 16 hours, that occurs between two major sleep periods and it degrades task performance [This acute, or transient, performance decrement should be eliminated after a regular sleep period.]
- CUMULATIVE MENTAL FATIGUE is a factor when the individual's diminished mental capability is due to disturbed or shortened major sleep periods between two or more successive major waking, duty or work periods and it degrades task performance. [One major sleep period will not eliminate cumulative fatigue.]
- CHRONIC MENTAL FATIGUE is a factor when the individual is exposed frequently during at least one month to multiple periods of prolonged wakefulness, excessive work hours, disturbed or shortened major sleep periods, unresolved conflicts, or prolonged frustration and it degrades task performance. An individual must display, concurrently, four or more of the following symptoms: the desire to sleep, apathy, substantial impairment in short-term memory or concentration; muscle pain; multi-joint pain without swelling or redness; headaches of a new type, pattern or severity; unrefreshing sleep; and post-exertion malaise lasting for more than 24 hours. The symptoms must have persisted or recurred for at least one month. [It is not eliminated by any number of sleep periods without first removing the cause.]
- TASK-SPECIFIC FATIGUE. Our understanding of task-specific fatigue has its roots in the study of physical work and acute muscle fatigue: repeated, demanding muscular work causes muscle fatigue and the need for recovery. With the advent of automation, research began in the 1980s to understand the effects of "technostress." Work that is assisted by automation generally requires sensorimotor operations that place demands upon specific, fine-motor and visual functions. Some of the work requires vigilance, and some requires repetitive operations. Thus, we observe task-specific fine-motor muscular fatigue, visual fatigue, vigilance failures, monotony, and repetitive-stress injuries in the automated workplace. Each of these problems requires

[1] Definitions coordinated between AFRL/HEPF and AFSC/SEFL, Sep 2004, in response to an Inspector General recommendation (AFIA, 2004).

task-specific short-term and long-term specific fatigue management and recovery considerations.

Some argue that task-specific fatigue is actually habituation to a task and is not, truly, fatigue. Others may argue that a task is simply boring, and that this is not fatigue. Whatever it is called, the fact is that task performance declines as time performing the task continues. This is the same overall pattern that we have with wakefulness: performance declines as time awake continues. These two effects can be additive.

If the individual cannot change tasks, then the effects of task-specific fatigue cannot be avoided. They may only be recognized and managed. Fortunately, it seems as though aircrews and other weapon system operators do not suffer very much from task-specific fatigue when they are in the control loop. They may suffer from sleepiness and reduced levels of vigilance that affect task performance, but their focus on the overall task seems to remain intact. Whether this is due to motivation, automated behaviors and/or other factors is not known. However, humans who monitor automated systems may fall prey to vigilance decrements, boredom, habituation, and/or task-specific fatigue.

OPERATIONAL RISK MANAGEMENT

"Operational risk management [ORM] is a decision-making process to systematically evaluate possible courses of action, identify risks and benefits, and determine the best course of action for any given situation. ORM enables commanders, functional managers, supervisors, and individuals to maximize operational capabilities while limiting all dimensions of risk by applying a simple, systematic process appropriate for all personnel and functions both on- and off-duty. Appropriate use of ORM increases both an organization's and individual's ability to accomplish their mission, whether it is flying an airplane in combat, loading a truck with supplies, planning a joint service exercise, establishing a computer network, or driving home at the end of the day. Application of the ORM process ensures more consistent results, while ORM techniques and tools add rigor to the traditional approach to mission accomplishment, thereby directly strengthening the Air Force's warfighting posture." (AFI 90-901, *Operational Risk Management*, 1 Apr 2000)

The ORM process follows a 6-step sequence guided by four principles. The six steps are: identify the hazards, assess the risk, analyze risk control measures, make a control decision, implement risk controls, and supervise and review. These steps are addressed below.

IDENTIFICATION OF FATIGUE HAZARDS

In ORM, a *hazard* is a condition with the potential to cause illness, injury, death, property damage, or mission degradation. Hazard identification is a continual process and is an inherent responsibility of every individual involved in the operation. Using the research literature as a guide, we listed the known, primary physiological and psychological effects of fatigue in Table 1. Each effect has the potential to cause harm in military operations and, thus, is a hazard. Modifications to this list should be made whenever indicated by new research or operator experience. One day, the risk of each of these hazards may become quantifiable.

The specific effects listed here are aligned approximately with the kinds of cognitive and physiological tests used in research that have been shown to be sensitive to the fatigued state. The extrapolation of the listed effects to safety-sensitive jobs is explained through examples in the Glossary (Appendix B). Safety-sensitive jobs include such things as operating a vehicle (land, air, or water), making command and control decisions, operating a weapon, guarding public safety, etc.

Table 1. Fatigue-related effects (defined further in Appendix B).

FATIGUE-RELATED EFFECTS
1. Individual Differences
2. Basic Cognitive Functions
2a. Working memory impairment
2b. Anterograde amnesia
2c. Retrograde amnesia
2d. Cognitive impairment
2e. Slowed response time (RT) and reduced response accuracy
2f. Impaired manual control
2g. Vigilance impairment
2h. Narrowed attention
2i. Hypnagogic hallucinations
3. Complex Cognitive Functions
3a. Willingness to accept greater risk
3b. Loss of situation awareness
4. Mood & Motivation Impairment
5. Physiological
5a. General malaise
5b. Reduced aerobic capacity
5c. Drowsiness
5d. Sleep debt and need for recovery sleep
5e. Falling asleep on the job
5f. Dizziness
5g. Decreased altitude tolerance
5h. Decreased thermal tolerance
5i. Decreased acceleration tolerance
5j. Cardiovascular health effects
5k. Gastrointestinal health effects
6. Physiological Interactions
6a. Worsening of alcohol effects
6b. Modulation of drug effects
7. Interpersonal/Team Interactions
7a. Reduced interpersonal communications
7b. Impairment of shared situation awareness

ASSESSMENT OF FATIGUE RISKS

Once hazards have been identified, the risk of each hazard must be assessed and quantified. While each of the effects in Table 1 is a hazard under the ORM definition, above, in the past it was virtually impossible to quantify the risk associated with each effect. Research had just not progressed far enough.

However, the fact that each of the effects in Table 1 has the potential to cause harm leads easily to the conclusion that needless fatigue, in general, is to be avoided in military operations. Thus, we chose to quantify the risks associated with the five types of fatigue defined above: physical fatigue, circadian effects, acute fatigue, cumulative fatigue, and chronic fatigue.

We had laid the groundwork for this approach in a previous effort. Investigators of workplace and transportation accidents and incidents seldom had the instruments or expertise required to determine whether human fatigue might have contributed to the mishap (AFIA, 2004). A Fatigue Checkcard and associated protocol were designed as a screening tool to fill this need (Miller, 2005). The Fatigue Checkcard was designed in part using the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model (Hursh et al., 2004), implemented as the Fatigue Avoidance Scheduling Tool (*FAST*™) software. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm.

Briefly, using the Checkcard, a mishap investigator could generate a fatigue-likelihood score based upon seven simple observations: length of prior wakefulness, amount of prior sleep for the preceding 72 hours, time of mishap, number of night shifts in preceding 30 days, time zone change and days in zone, types of human errors associated with mishap, and estimated physical exertion across the work period of interest. Because the Checkcard was an after-mishap rating instrument, and the ORM process is a pre-mission rating instrument, the sixth observation (type of human error associated with the mishap) was not applicable to the ORM process. The six remaining scores accounted well for the likelihood that one or more of the five types of fatigue may have been present at the time of the mishap. Obviously, this kind of score is transferable to the ORM process.

FATIGUE INDICATORS

At about the same time that this work was being accomplished (2004); the National Transportation Safety Board established a training course titled "Investigating Human Fatigue Factors" at its Training Center.[2] The course was designed and taught by Drs. David F. Dinges and Mark R. Rosekind, well-known sleep and fatigue scientists. In addition to case studies and hands-on exercises, the course provided participants "with information and guidance to evaluate the role human fatigue plays in accident causation." It covered "fatigue-related issues including sleep length, sleep disorders, circadian rhythms, work schedules, and the effects of fatigue on performance and alertness." The instructions and guidelines provided in that course indicated general acceptance of limits for five fatigue indicators, limits that raise "red indicators" with respect to the likelihood that human

[2] The NTSB Training Center is the training facility for the National Transportation Safety Board, an independent federal agency that investigates all civil aviation accidents in the United States and selected accidents in other modes of transportation. The Training Center provides training for NTSB investigators and others from the transportation community to improve their practice of accident investigation techniques. The curriculum promotes independent, objective, and technically advanced accident investigations that will enhance the safety of all modes of transportation. (http://www.ntsb.gov/Academy/about.htm, May 2008)

cognitive performance is likely to be impaired by fatigue. The SAFTE modeler, Dr. Steven R. Hursh, inserted the indicators and limits into SAFTE and NTI inserted them into *FAST*™ (Dr. Steven R. Hursh, personal communication, May 2008). When set limits were exceeded for any one of these five indicators, a "red flag" image for that indicator was displayed in the "Dashboard" component of the *FAST*™ software. The latter five indicators (flags) are:

- Amount of sleep in the last 24 hours
- Cumulative sleep debt
- Hours awake since the last major sleep period
- Time of day
- Amount of jet lag or shift lag

Our second attempt to use a quantitative, applied model of fatigue and well-accepted fatigue countermeasures in the context of operational risk management, reported here, focuses upon these five generally accepted indicators and their limits that are very similar to the indicators generated by the Checkcard work. Each of the five indicators is discussed, below.

Amount of Sleep in the Last 24 Hours

The limit for amount of sleep is eight hours. Thus, if an individual has acquired fewer than eight hours of sleep in the immediately-preceding 24 hours, then mental fatigue is likely to have reached a dangerous level. For a full exposition of why eight hours was selected as the break-point, the reader is referred to the print and electronic media provided by the National Sleep Foundation (NSF). For example, NSF has noted:

> [T]here is no "magic number." Not only do different age groups need different amounts of sleep, but sleep needs are also individual. Just like any other characteristics you are born with, the amount of sleep you need to function best may be different for you than for someone who is of the same age and gender. While you may be at your absolute best sleeping seven hours a night, someone else may clearly need nine hours to have a happy, productive life...
>
> Another reason there is "no magic number" for your sleep results from two different factors that researchers are learning about: a person's basal sleep need – the amount of sleep our bodies need on a regular basis for optimal performance – and sleep debt, the accumulated sleep that is lost to poor sleep habits, sickness, awakenings due to environmental factors or other causes. Two studies suggest that healthy adults have a basal sleep need of seven to eight hours every night, but where things get complicated is the interaction between the basal need and sleep debt. For instance, you might meet your basal sleep need on any single night or a few nights in a row, but still have an unresolved sleep debt that may make you feel more sleepy and less alert at times, particularly in conjunction with circadian dips, those times in the 24-hour cycle when we are biologically programmed to be more sleepy and less alert, such as overnight hours and mid-afternoon. (*How Much Sleep Do We Really Need?*, www.sleepfoundation.org, May 2008)

On the basis of the applicable research, discussed in this article and elsewhere, NSF published a table of sleep needs for different age groups. The sleep need for adults was specified as 7 to 9 hours. The middle of that range was chosen for use as a break point here.

Cumulative Sleep Debt

The limit for cumulative sleep debt is 10 hours. If an individual has more than 10 hours of cumulative sleep debt, then mental fatigue is likely to have reached a dangerous level. Ten hours is 25% more than one full night of sleep. Most fatigue scientists would agree that after missing an entire night of sleep (or the equivalent); you have a serious debt that needs to be restored. A simplistic method for calculating cumulative sleep debt follows. Work backward in 24-hour segments from the present time to the last time that the individual was fully "caught up" on their sleep. For example, they had slept at least eight hours per night for a week or so. Alternatively, work backward as far into the past as possible. For each 24-hour period, estimate the hours of sleep acquired. Subtract each estimate from eight hours. When too few hours of sleep have been acquired, then the difference will be positive. When "recovery" sleep has been acquired, the person will have slept more than eight hours and the difference will be negative. If the difference is negative, multiply it by two (because of our sleep physiology, we make up sleep faster than we lose it). Add the positive and negative values together to get the cumulative sleep debt. An example follows:

Day	Amount of Sleep	Difference from 8 Hours
Today	10 hours	-4 hours
Yesterday	6 hours	2 hours
Previous	6 hours	2 hours
Previous	7 hours	1 hour
Previous	8 hours	0 hours
Previous	7 hours	1 hour
Cumulative sleep debt:		2 hours

Hours Awake Since the Last Major Sleep Period

The limit for hours awake is 17. Thus, if an individual has been awake for more than 17 hours since the last major sleep period, then mental fatigue is likely to have reached a dangerous level. On a day-to-day basis, the individual is expected to acquire 8 hours of sleep and to be awake for 16 hours. However, on one given day on which there is no cumulative sleep debt, research data suggest that a dangerous level of mental fatigue is not likely to be reached until 17 hours of wakefulness. What is a major sleep period? Generally, more than three hours of continuous, excellent-quality sleep.

Time of Day

The period of concern is between midnight and 06:00 *on the body clock*. If mental work is to be performed during this period, then mental fatigue is likely to be at a dangerous level. This phenomenon exists because of the normal, unavoidable, daily (circadian) rhythm in metabolic rate and body temperature. This rhythm reaches its low point at about 04:00 in a person without jet lag or shift lag.

Amount of Jet Lag or Shift Lag

The break point is three hours of lag. Thus, if the body clock (circadian rhythm) is more than three hours out of synchrony with local time, then mental fatigue is likely to be at a dangerous level. Jet lag occurs when the body travels across time zones faster than one zone per 24 hours. Shift lag occurs when the work period occupies the normal, nocturnal sleep period, without a time zone change. When there is more than three hours of difference, metabolic, temperature and hormonal rhythms in the body are disturbed with respect to the local day-night cycle and with respect to each other. The result is a feeling of *malaise*, or mild illness.

A simplistic method for calculating jet lag follows. Work backward in 24-hour segments from the present time to the last time that the individual had spent at least two weeks in one single time zone. For each 24-hour segment, record the number of time zone changes that occurred. For each day after a change, subtract a day of lag. In the following example, a 6-zone change occurred 2 days ago. The amount of jet lag on the following day (yesterday) was 6 hours and on the present day (today) is 5 hours.

Previous Days	Number of Time Zones	Jet Lag
0 (today)	0	5 hours
1 (yesterday)	0	6
2	6	0
3	0	0
4	0	0
5	0	0

A simplistic method for calculating shift lag follows. Work backward in 24-hour segments from the present time to the time at which a change from day shift to night shift (or night shift to day shift) occurred. For each 24-hour segment, record the number of hours difference in sleep start time. For each day after the change, subtract a day of lag. In the following example, a change from swing shift to night shift occurred 5 days ago. As a result, the individual's bedtime changed from midnight to 08:00 (8-hour shift). The amount of shift lag on the following day was 8 hours and on the present day (today) is 4 hours.

Previous Days	Number of Hours Shifted	Shift Lag
0 (today)	0	4 hours
1 (yesterday)	0	5
2	0	6
3	0	7
4	0	8
5	8	0

The five fatigue indicators represented by the indicators in the FAST dashboard are defined in Table 2 along with their abbreviation.

Table 2. FAST fatigue indicator indicators and their abbreviations.

Fatigue Indicator or Indicator	Abbreviation
Less than eight hours of sleep in the last 24 hours	< 8
A cumulative sleep debt (in the sleep reservoir) of more than eight hours	> 8
More than 17 hours of continuous wakefulness	> 17
Time of day between one and seven hours before the predicted time of awakening on the body clock, i.e., the pre-dawn hours. For a person who slept typically from 22:00 to 06:00, this would be 23:00 to 05:00.	Pre
The body clock is out of phase; it is in the process of shifting by more than three hours	> 3

QUANTITATIVE ANALYSES OF FATIGUE RISKS

Three questions were posed about the usefulness of the "fatigue indicators" in the ORM of fatigue effects. First, in what manner and frequency did the indicators appear in schedules? Second, how did the indicators correlate with percent cognitive performance effectiveness calculated as the output of SAFTE and *FAST*™? Third, did the indicators offer any additional fatigue information not captured in the performance effectiveness measure? This section addresses these three questions.

METHODS

Observations of indicator onset and offset were made in five different schedules in *FAST*™ (version 1.6.00T):

- Complete **sleep deprivation**. This was the default new schedule in *FAST*™. Percent performance effectiveness (PE) started very high and oscillated down to zero in several days.
- **Sleep restriction**. Typical sleep was assumed to be 23:00-07:00. In this schedule, sleep was restricted to 01:30-04:30. Percent PE started very high and, by day 14, had oscillated down such that 50% was the highest PE reached during the day.
- **Jet lag**. Typical sleep was 23:00-07:00. In this schedule, a 6-hour flight from Los Angeles to London occurred from 12:00 to 18:00, Los Angeles time on day 0. All observations were in Los Angeles time (PST) and were made across the subsequent six days. Major sleep periods were of 4, 6, 7, 8, and 8-hour lengths, respectively, with one hour phase advance per day for the start time from 0400Z and with a maximum end time of 0900Z (Z represented U.K. local time).
- The pilot on a 4-day **mishap mission.** Typical sleep was assumed to be 23:00-07:00; all observations in California time (PST).
    - The mission was comprised of three duty periods with the crew going into crew rest between duty periods. In the first duty period, the crew departed their home base, Travis AFB, CA, made a stop at Randolph AFB, TX, and flew on to Pope AFB, NC. At Pope, the crew laid-over for crew rest. In the second duty period, they proceeded further eastward to Lajes AB in the Azores where the crew again entered into extended crew rest. During the third duty period, the mission proceeded from Lajes onto Ramstein, Germany, where the mishap occurred during landing.

- The first nine days of the Continental *rota* **shiftwork** plan; DDSSNNNOO; typical sleep from 22:00-06:00; 8-hour shifts with shift changes at 07:00, 15:00 and 23:00

Observations were made sequentially and data were acquired each time an indicator came on or went off. Each schedule was scanned sequentially by advancing the cursor in FAST™ by 30-minute increments with the Dashboard function providing indicator information. When an indicator changed, a minute-by-minute search was used to pinpoint the minute in which the change occurred. The data recorded from the Dashboard included time of day (T), decimal day/time (Tn; 0-based), percent cognitive performance effectiveness (PE), lapse likelihood (Lapse), percent response time (RT), percent sleep reservoir (Res), the absence or presence (0, 1) of each of the five indicators (< 8, > 8, > 17, pre, and > 3, respectively) and the sum of the indicators presented (Fs; 0 to 5). These recorded observations reflect only the minute at which an indicator changed. The percentages and lapse likelihood changed immediately after each observation even though the indicator status may not have changed.

RESULTS

The observations for the sleep deprivation schedule are shown in Table 3. Indicator changes occurred from 23:00 on day 0 through midnight at the beginning of day 2, with PE ranging from 90% to 59%. The < 8 indicator came on first and stayed on. The > 17 indicator came on second and stayed on. The > 8 indicator came on third and stayed on. The Pre indicator came on periodically. The > 3 indicator never came on since there was no large perturbation of the body clock. The greatest sum of indicators was four.

Table 3. Indicator observations for sleep deprivation schedule.

T	Tn	PE	Lapse	RT	Res	< 8	> 8	> 17	Pre	> 3	Fs
23:00	0.96	90%	1.5	111%	93%	**1**					1
00:00	1.00	85%	2.3	118%	82%	1		**1**	1		3
06:00	1.25	70%	5.2	143%	76%	1		1			2
07:00	1.29	71%	4.9	140%	75%	1	**1**	1			3
00:00	2.00	59%	8.3	169%	57%	1	1	1	1		4

Note: T, time of day; Tn, decimal day/time; PE, percent cognitive PE; Lapse, lapse index; RT, percent response time; Res, percent sleep reservoir; absence or presence of the five indicators (< 8, > 8, > 17, pre, and > 3); Fs, sum of the five indicators.

The observations for the sleep restriction schedule are shown in Table 4. Indicator changes occurred from 23:00 on day 0 through 00:33 at the beginning of day 2, with PE ranging from 90% to 73%. The < 8 indicator came on first and stayed on. The > 17 indicator came on at midnight at the beginning of day 1, but went off an hour and a half later at the first minute of sleep (blue text). It came on again later in the schedule. The > 8 indicator came on third and stayed on. The Pre indicator came on periodically. The > 3 indicator never came on since there was no large perturbation of the body clock. The greatest sum of indicators was four.

Table 4. Indicator observations for restricted sleep, three hours per night from 01:30 to 04:30.

T	Tn	PE	Lapse	RT	Res	< 8	> 8	> 17	Pre	> 3	Fs
23:00	0.96	90%	1.5	111%	93%	**1**					1
00:00	1.00	85%	2.3	118%	82%	1		1	1		3
01:30	1.06	77%	3.6	129%	81%	1			1		2
06:11	1.26	85%	2.3	118%	90%	1					1
20:13	1.84	89%	1.7	113%	75%	1	**1**				2
21:30	1.90	86%	2.0	116%	74%	1	1	1			3
00:33	2.02	73%	4.6	137%	70%	1	1	1	1		4

Note: Blue text indicates an observation taken during a sleep period.

The observations for the jet lag schedule are shown in Table 5. Indicator changes occurred from 00:00 at the beginning of day 1 through 05:14 on day 4, with PE ranging only from 89% to 83%. The < 8 indicator was on during days 1 through 3, and the > 8 indicator was on just briefly during day 3. The > 3 indicator did not come on until the last minute of the wake period on day 3, at which time the body clock's phase advance was about 40 minutes. The Pre indicator came on periodically. The greatest sum of indicators was three.

Table 5. Indicator observations for jet lag: 6-h flight from L.A. to U.K., 12:00 to 18:00 on day 0.

T	Tn	PE	Lapse	RT	Res	< 8	> 8	> 17	Pre	> 3	Fs
00:00	1.00	89%	1.7	113%	86%				1		1
03:00	1.13	82%	2.7	122%	93%	1			1		2
18:59	3.79	87%	2.0	115%	73%	1	1			1	3
19:51	3.83	88%	1.7	113%	75%	1				1	2
19:58	3.83	89%	1.7	113%	75%					1	1
23:19	3.97	85%	2.3	118%	82%				1	1	2
05:14	4.22	83%	2.5	120%	88%					1	1

Notes: 1. Blue text indicates an observation taken during a sleep period.
2. All observations were made in "Base" (California) time.

The observations for the mishap mission schedule are shown in Table 6. Indicator changes occurred from 05:30 at initial waking on day 0 through 05:33 on day 3, with PE ranging from 93% to 67%. The < 8, Pre and > 3 indicators were on periodically. The initial occurrence of the > 3 indicator was at the last waking minute of the 2nd major wake period. Subsequently, it switched on and off at the last minute of major wake periods. The > 8 indicator came on about an hour and a half before the mishap. The > 17 indicator never came on. The greatest sum of indicators was three.

Table 6. Indicator observations for the mishap mission schedule. All observations were made in "Base" (California) time.

T	Tn	PE	Lapse	RT	Res	< 8	> 8	> 17	Pre	> 3	Fs
05:30	0.23	88%	1.7	113%	98%	1			1		2
06:00	0.25	93%	1.1	108%	98%	1					1
22:59	0.96	90%	1.4	111%	84%						0
23:56	1.00	88%	1.8	114%	85%				1		1
03:45	1.16	80%	3.1	125%	92%	1			1		2
05:47	1.24	85%	2.3	118%	90%	1					1
07:59	1.33	87%	1.9	114%	87%	1				1	2
09:44	1.41	92%	1.2	109%	89%					1	1
17:59	1.75	93%	1.1	107%	81%						0
22:45	1.95	84%	2.4	119%	78%	1					1
23:29	1.98	80%	3.1	125%	77%	1				1	2
23:30	1.98	80%	3.1	125%	77%	1			1	1	3
05:43	2.24	81%	2.9	123%	87%	1				1	2
17:44	2.74	91%	1.4	110%	80%					1	1
20:14	2.84	93%	1.1	108%	80%						0
23:42	2.99	82%	2.8	122%	79%				1		1
01:30	3.06	73%	4.6	138%	78%	1			1		2
03:57	3.16	67%	6.1	150%	75%	1	1		1		3
05:33	3.23	67%	5.9	149%	73%	1	1				2
09:35	3.40	71%	mishap								2
Note: Blue text indicates an observation taken during a sleep period.											

The observations for the shift work schedule are shown in Table 7. Indicator changes occurred from 23:21 on day 3 through 22:37 on day 8, with PE ranging from 92% to 65%. The < 8 indicator came on at the beginning of day 5, the first night shift, and stayed on until the nocturnal sleep period at the beginning of day 8. All of the other four indicators came on periodically. The greatest sum of indicators was four, on day 5.

Table 7. Indicator observations for the shiftwork schedule (DDSSNNNOO).

T	Tn	PE	Lapse	RT	Res	< 8	> 8	> 17	Pre	> 3	Fs
23:21	3.97	86%	2.1	117%	83%				1		1
23:58	5.00	86%	2.1	117%	83%				1		1
00:00	5.00	85%	2.2	117%	83%	1			1		2
01:00	5.04	80%	3.0	124%	82%	1		1	1		3
06:04	5.25	71%	5.0	141%	77%	1		1			2
07:38	5.32	73%	4.6	137%	75%	1	1	1			3
07:59	5.33	73%	4.5	137%	75%	1	1	1		1	4
08:00	5.33	73%	4.5	136%	75%	1	1			1	3
08:09	5.34	74%	4.3	135%	75%	1				1	2
19:59	5.83	92%	1.2	109%	79%	1					1
00:27	6.02	82%	2.8	122%	79%	1			1		2
04:33	6.19	66%	6.1	151%	75%	1	1		1		3
06:42	6.28	67%	6.1	150%	73%	1	1				2
07:59	6.33	68%	5.6	147%	71%	1	1			1	3
08:50	6.37	74%	4.3	135%	75%	1				1	2
19:59	6.83	89%	1.7	113%	76%	1					1
01:10	7.05	81%	3.0	124%	78%	1			1		2
04:03	7.17	68%	5.8	148%	75%	1	1		1		3
07:26	7.31	65%	6.4	153%	71%	1	1				2
07:59	7.33	66%	6.2	152%	71%	1	1			1	3
08:58	7.37	73%	4.6	138%	75%	1				1	2
19:54	7.83	86%	2.0	116%	75%	1	1			1	3
21:59	7.92	86%	2.0	116%	73%	1	1				2
23:07	7.96	87%	1.9	115%	75%	1					1
01:50	8.08	83%	2.6	120%	81%	1			1		2
02:00	8.08	83%	2.6	121%	81%				1		1
07:59	8.33	84%	2.5	120%	88%						0
20:52	8.87	87%	1.9	115%	75%		1				1
22:37	8.94	89%	1.7	113%	75%						0

Note: Blue text indicates an observation taken during a sleep period.

Scenario Statistics
The five sets of observations provided 67 unique sets of data. (The first two observations in Table 2 were replications of the first two in Table 1 and were deleted for all statistics.) The remaining 65 observations were then examined statistically to identify consistent patterns of indicator appearance and correlations among the variables.

Indicator frequency within the five scenarios varied dramatically. In the 65 observations, 60 contained one or more indicators and five had none. With 121 total indicator occurrences, the < 8 indicator appeared 48 times while the > 17 indicator appeared only 10 times as shown in Figure 1. Examining the order of appearance shown in Figure 2, the < 8 and Pre indicators generally appeared first or second. The > 17 indicator generally appeared third and the > 8 indicator fourth. The > 3 indicator appeared later in scenarios and was therefore infrequent.

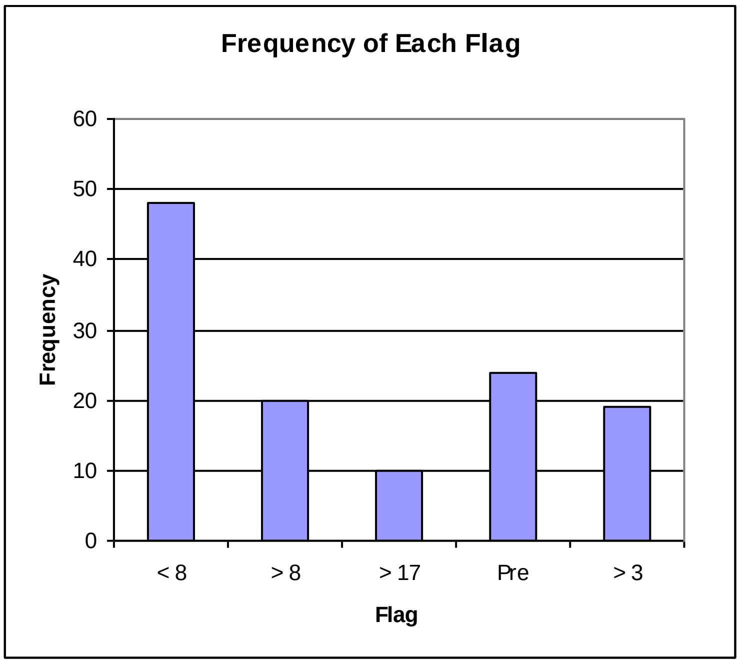

Figure 1. The frequency of occurrence of each indicator is shown across all five scenarios.

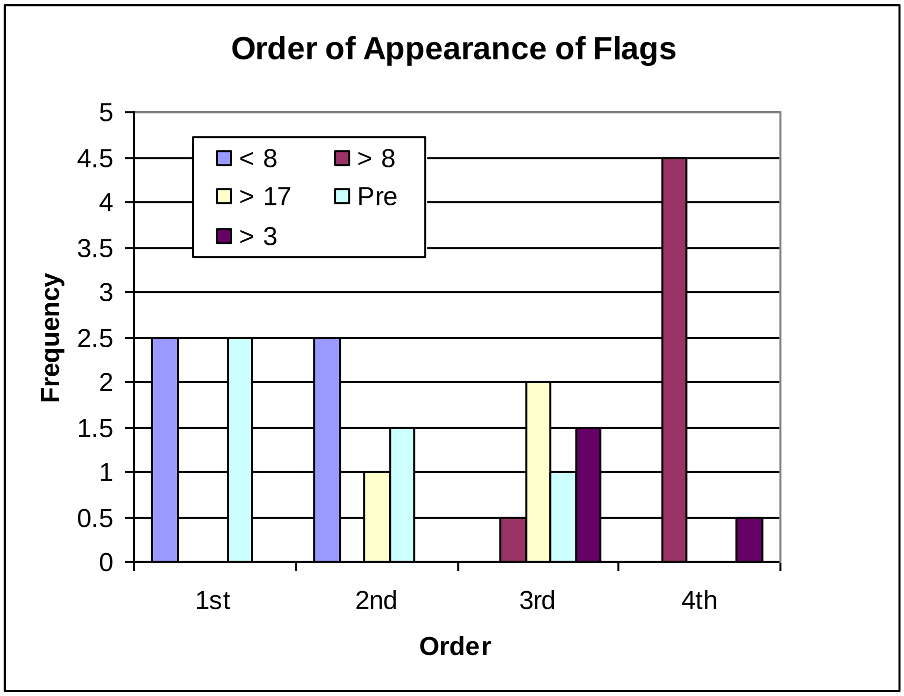

Figure 2. The order of appearance of each indicator is shown across all five scenarios.

Examining the occurrence of indicators with or without others, we found that the < 8 indicator occurred by itself most frequently and that the > 17 indicator never occurred singly as shown in Table 8. The co-occurrence of each indicator with < 8 is shown in Table 8. The < 8 indicator was present in all pairs except one in which the Pre and > 3 indicators appeared together (not shown in table). Counting the co-occurrence of the Pre and > 3 indicators, two indicators appeared together on 24 occasions. Examining the co-occurrences of three and four indicators, it was discovered that the < 8 indicator was present in every case. Table 9 shows the co-occurrence of three and four indicators.

Table 8. Frequency of indicators with < 8 or no others.

	< 8	> 8	> 17	Pre	> 3	Total
Single Indicator	8	1	0	6	4	19
With < 8 Indicator	-	5	2	9	7	23

Table 9. Occurrence of the < 8 indicator with two and three other indicators.

Indicators	>8 & >17	>8 & >Pre	>8 & >3	>17 & Pre	Pre & >3	>8 & >17 & Pre	>8 & >17 & >3
Frequency	3	3	5	2	1	2	1

Interestingly, the < 8 indicator appeared in 48 of 60 (80%) indicator onset events leaving only 12 events in which other indicators occurred without it. Of the 12 cases, all were single indicator occurrences except one. Considering the > 17 indicator, one may not usually reach 17 hours awake without having less than 8 hours of sleep in the last 24 hours (17+8=25), which sets the < 8 indicator. Therefore, the > 17 indicator always occurs with the < 8 indicator or with it and other indicators.

After carefully examining indicator onsets and offsets, we need to consider the relationships of other variables, including the indicators, to PE. Across all schedules, Table 10 shows the correlations for the interval variables with percentage cognitive performance. Performance effectiveness was correlated with both lapse likelihood and RT at $r = -0.993$. This was expected, since the latter two measures are direct transforms of effectiveness. Effectiveness was correlated at $r = 0.572$ with the level of the sleep reservoir, a variable that contributes to the calculation of effectiveness.

Table 10. Correlations between percent cognitive performance effectiveness and other measures.

Measure	Pearson r
Lapse likelihood	-0.993
Reaction time	-0.993
Sleep reservoir level	0.572
Sum of indicators	-0.665

The sum of indicators correlated with PE at $r = -0.665$, indicating about 44.2% shared variance between the two measures. A scatter plot of this relationship is shown in Figure 3 and the distribution of data appeared to be relatively homoscedastic.

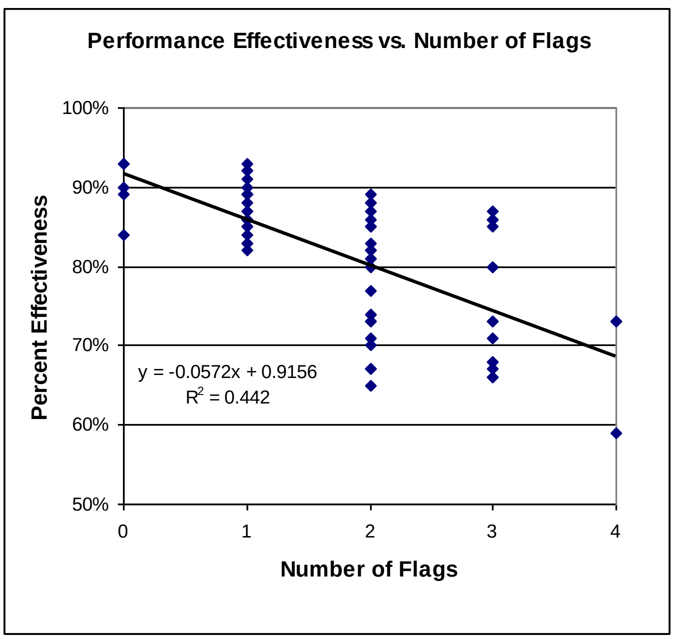

Figure 3. Scatter plot for percentage cognitive performance effectiveness as a function of sum of indicators (n = 65, r = -0. 665).

To investigate further their relationship to fatigue, indicator onset and PE were examined. Figure 4 shows the mean PE value when each indicator is present. Although the indicator count was highly variable, the mean PE for each indicator appears to be fairly homogeneous. As shown in Figure 4, means only vary from 73 to 81% and the standard deviations run from 8 to 9%. However, at each data point there are potentially other indicators present. For example, since the < 8 indicator is present with 48 of the 60 observations, 68%, the PE for it will affect the means for the other indicators. Because the > 17 indicator never occurs alone, its 10 occurrences are affected by the PE for all the other indicators (2-≤8, 1-≥3, 2-≤8 & ≥8, 2-≤8 & Pre, 2-≤8 & ≥8 & Pre, and 1-≤8 & ≥8 & ≥3). Examining the 19 occurrences of solo indicators, we found the means for each indicator ranged from 86 to 89% showing great consistency. Plotting the PE means, minimums, and maximums for the number of indicators is shown in Figure 5. This is another way of looking at the information contained in Figure 3.

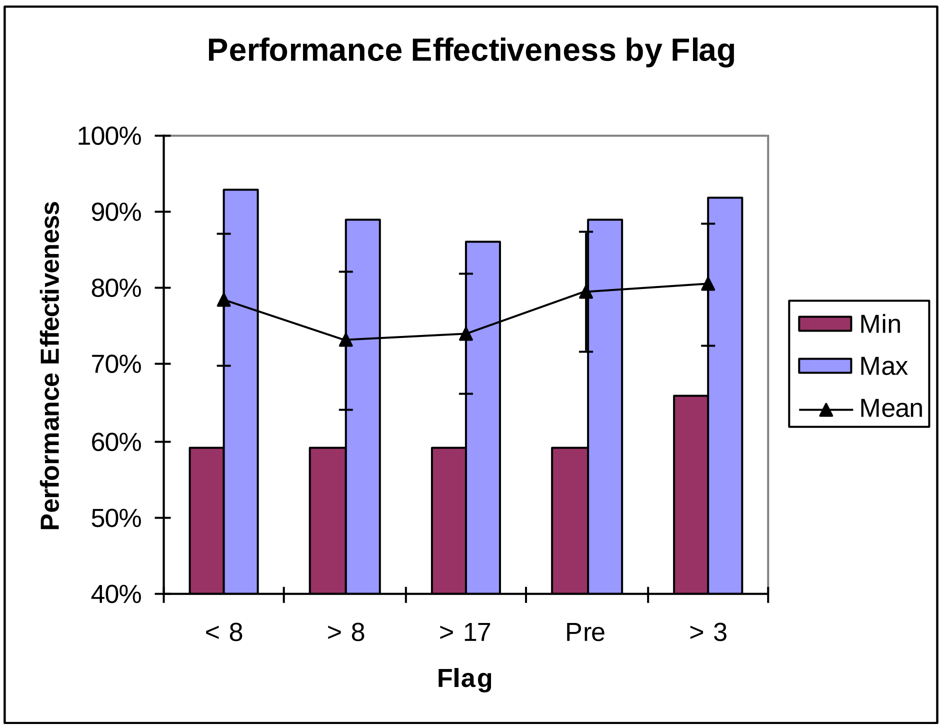

Figure 4. This histogram shows mean PE during the presence of the various indicators. Also shown are the minimum PE, maximum PE, and the standard deviation.

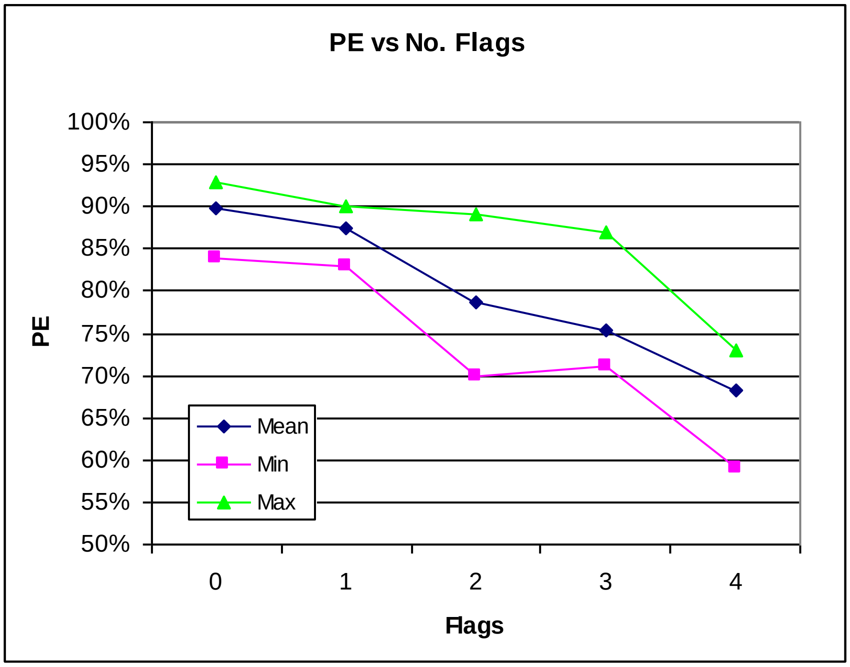

Figure 5. A plot showing the PE means, minimums, and maximums for increasing numbers of indicators.

Summary of Findings and Next Step

These observations and correlations suggested several conclusions. First, it appeared likely that the dynamic range of the sum of indicators was somewhat limited. In the five schedules used here, it seldom reached four indicators and never reached five indicators. Second, it appeared that the sum of indicators was somewhat independent of percent cognitive PE, with a shared variance of about 44.2%.

Finally, because of the look-back calculation of acrophase shift, the onset timing of the switch for the out-of-phase indicator (> 3) was counterintuitive. Intuitively, one might expect the > 3 indicator to come on as soon as at least three time zones have been crossed. (Of course, this expectation does not generalize well to shift work rotations.) *FAST™* allowed the user to see that the indicator came on when acrophase had phase-shifted less than an hour. Unfortunately, *FAST™* did not show clearly the relationship that generated the presence of the > 3 indicator.

The > 3 switch was set to turn on the indicator at the arithmetic calculation point at the end of a major wake period. Thus, in the jet lag schedule, the indicator did not come on until the end of the 3rd major wake period after the 6-h time zone transition, and in the mishap mission schedule, it did not come on until the end of the second duty day. It is likely that these are the approximate times, physiologically, when the malaise of jet lag would begin to affect cognitive performance.

The delayed onset of the > 3 indicator was at least part of the reason that it was unlikely that all five indicators would be displayed together. Even a combination of the first two schedules, above, failed to elicit a 5-indicator display. For example, the trip from L.A. to the

U.K was entered in *FAST*™ as in the jet lag schedule. Only two hours of sleep were allowed upon arrival, with subsequent total sleep deprivation as in the first schedule. The greatest sum of lags was still four.

Factor Analysis

Since our goal was to quantify fatigue for use in ORM, we needed to insure that adding the fatigue indicators to the PE score actually improved the fatigue estimate. That is, given that PE accounts for a specific proportion of performance variability due to fatigue,[3] does the number of fatigue indicators add to the amount of variance we may account for, or is it just another way of accounting for the same variance? One way to answer that question is to conduct a factor analysis of the indicators along with PE. Factor analysis is often used to identify a small number of factors that explain most of the variance observed in a much larger number of manifest variables. If the indicators contribute to an additional factor or two, their contribution to predicting fatigue would account for additional variance over and above PE. With the data from the five scenarios listed above, sufficient data existed to conduct such an analysis.

All the data points for PE and each of the five indicators were used after removing the two duplicate cases repeated in the restricted sleep scenario. The remaining 65 rows were factored using the Factor Analysis program in SPSS11.5 for Windows (SPSS, Inc., Chicago, IL). The program uses the principal components method of extraction. It begins by finding a linear combination of variables (a component) from the full matrix of correlations that accounts for as much variation in the original variables as possible. It then finds another component that accounts for as much of the remaining variation as possible and is uncorrelated with the previous component, continuing in this way until there are as many components as original variables. Usually, a few components will account for most of the variation, and those accounting for the small remaining variance are not considered. The cutoff for evaluating additional components can be made in two ways. In one, only eigenvalues greater than 1 are used. In the other, a Screen plot is used to determine when new factors are no longer contributing to the explanation of variance.

Once the minimum set of components have been selected, the Varimax method is used to rotate the components into factors that are, hopefully, interpretable. Turning to our analysis, a table of communalities is initially presented, Table 11. Initial communalities are estimates of the variance in each variable accounted for by all components or factors. For principal components extraction, this is always equal to 1.0 for correlation analyses. Extraction communalities are estimates of the variance in each variable accounted for by the components. The communalities in this table were sufficiently high, indicating that the extracted components represented the variables well. If any communalities are very low in a principal components extraction, you may need to extract another component.

[3]Sleepiness will cause performance to slow or stop for brief periods, making work output highly variable across time.

Table 11. Communalities.

Variables	Initial	Extraction
PE	1.000	.705
< 8	1.000	.496
> 8	1.000	.613
> 17	1.000	.421
Pre	1.000	.653
> 3	1.000	.651

The variance explained by the initial solution, initial eigenvalues, and extracted components are displayed in Table 12. The Total column gives the eigenvalue, or amount of variance in the original variables accounted for by each component. The Percentage of Variance column gives the ratio of the variance accounted for by each component to the total variance in all of the variables. The Cumulative Percentage column gives the percentage of variance accounted for by the first n components. For example, the cumulative percentage for the second component is the sum of the percentage of variance for the first and second components. For the initial solution, there are as many components as variables, and in a correlations analysis, the sum of the eigenvalues equals the number of components.

Table 12. Total Variance Explained

Component	Initial Eigenvalues		
	Total	Percentage of Variance	Cumulative Percentage
1	2.129	35.48	35.48
2	1.410	23.50	58.98
3	0.818	13.64	72.62
4	0.681	11.36	83.97
5	0.648	10.81	94.78
6	0.313	5.22	100.00

The variance explained by the Varimax solution, the percentage explained, and rotated components are displayed in Table 13. Components with eigenvalues greater than 1.0 became the first two principal components and were used in the rotated solution. They explained nearly 59% of the variability in the original six variables, leaving a 41% loss of information. The rotation maintains the cumulative percentage of variation explained by the extracted components, and, in this case, hardly changed the variation over the components. The lack of change in the individual totals suggested that the un-rotated component matrix should be directly interpretable.

Table 13. Total Variance Explained by the Rotated Components.

Component	Rotation Sums of Squared Loadings		
	Total	Percentage of Variance	Cumulative Percentage
1	2.13	35.47	35.47
2	1.41	23.51	58.98

Examination of the un-rotated component matrix, Table 14, provided us with the information to determine what the components represented. The first component was most highly correlated with PE, < 8, > 8, and > 17. However, > 17 is not as good a representative of the first component because it is also correlated with the second component. The second component was most highly correlated with Pre and > 3. Looking at the variables that load on component 1, we may assign it the label, Sleep Reservoir Factor, whereas component 2 may be labeled the Circadian Disruption Factor.

Table 14. Un-rotated Component Matrix.

Variable	Component	
	1	2
PE	-0.839	0.028
< 8	0.700	0.077
> 8	0.755	0.208
> 17	0.601	-0.246
Pre	0-.014	-0.808
> 3	0-.064	0.804

Table 15 groups the variables and their loadings, making it easier to see these relationships. Although negative loadings are not typically seen in the final rotated components of a factor analysis with simple structure, in this case there is a simple explanation (MacCallum, 1993). Two major classes of simple structure exist: a simple structure with all positive loadings, positive manifold, and a structure with some negative loadings, without a positive manifold. A positive manifold is generated in a domain for which only zero or positive correlations exist. Negative correlations lead to the possibility of negative factor loadings. The factor transformation problem is much more straightforward when the factor structure has a positive manifold. The problem is that when variables show overlap through their correlations on the factors, the underlying or latent factors likely are also dependent.

Table 15. Variables Grouped by Factors.

Label	Fatigue Indicators Within Components	Factor Loading
	Sleep Reservoir Factor	
PE	Performance Effectiveness	-0.84
< 8	Less than eight hours of sleep in the last 24 hours	0.70
> 8	Cumulative sleep debt of more than eight hours	0.76
> 17	More than 17 hours of continuous wakefulness	0.59
	Circadian Disruption Factor	
Pre	Awake during pre-dawn hours	-0.81
> 3	Body clock out of phase	0.83

However, each attribute or underlying construct does not have to be dependent on only one factor. A common misconception is that simple structure is satisfied only by an independent cluster configuration. Cureton & D'Agostino (1983) indicated that each factor is to be interpreted in terms of whatever is common to the variables that have high loadings on that factor. If the interpretation is correct and consistent, the variables that have low but not near-zero loadings on the factor should then be interpretable as being somewhat affected by that factor. By the same reasoning, a bipolar factor is any rotated factor that has one or more negative, nonzero loadings in the column of variables that represent it. There are two types of bipolarity, nominal and intrinsic. A variable contributes a nominal bipolarity to at least one factor when it can be corrected by changing its sign throughout the original data matrix thus leading to a positive correlation with the variables with which it is associated and by reversing the scale and the name of the variable. For example, a “typing proficiency” test becomes a “typing deficiency” test. An intrinsic bipolarity can be recognized only in the component matrix, and it cannot be corrected.

In the case of the loading of PE on the Sleep Reservoir Factor, the PE variable is negatively correlated with the other three. The Pre (awake during predawn hours) loading on the Circadian Disruption Factor, has a correlation of -0.35 with body clock out of phase (> 3) and is shown in the component plot, Figure 6, to be tightly associated with the factor.

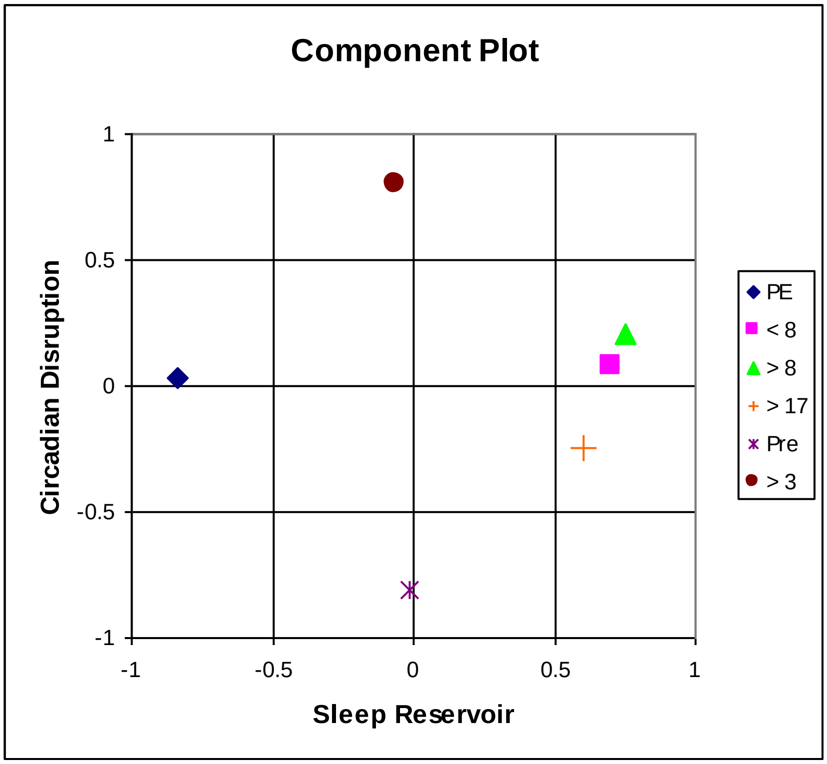

Figure 6. Scatter plot of loadings on the Sleep Reservoir and Circadian Disruption Factors.

Summary of Factor Analysis Results

The factor analysis of fatigue indicators and PE correlations resulted in two orthogonal factors. The presence of two factors demonstrated quantitatively the presence of an additional component to fatigue prediction that is missing from the PE measure. Further, the second factor, made up of two variables, was easy to interpret and label. Whereas the first factor was easily associated with the level of the sleep reservoir, the variables of the second factor were easily associated with circadian disruption. Although there were only two variables in that independent factor, they loaded heavily on the second factor (-.808, .804) and near zero on the first, (-.014 and -.064). Thus, it appeared that the use of the number of indicators in addition to the PE percentage would be likely to enhance risk assessment significantly beyond the use of PE percentage alone.

Addendum

We discussed two additional ideas that might have made our conjoint use of PE and indicators even stronger. First, we had used only the onset or presence of the indicators in our analyses. We believed that by combining this information with the PE variable that we could get a more reliable measure of fatigue ORM. However, by using just the presence of an indicator we limited our analysis to non-interval data, a 1, or a 0, for computing our correlations and analyses. Subsequently, we considered using the underlying values that trigger the indicators. For example, say the “More than 17 hours of continuous wakefulness” (> 17) indicator comes on. The other variables may or may not have their indicators up but we would capture their interval values. There may have been 7 hours of sleep in the last 24 and the sleep debt may have been 6, for example. This process would give us an interval variable instead of a binary variable for our analyses. Granted the variable that raised the indicator would always have the same value, but the others would be continuous giving more accurate correlations.

Second, to get a more representative assessment of each scenario, we could sample our scenarios at equal time intervals to get fully continuous measures for the indicator variables. We doubted that this sampling method would change our conclusion about using the indicators, but the process might make the case stronger for jointly using PE and the indicators.

Unfortunately, the four variables (excluding time of day) only appear to be monotonic and continuous. Two are non-continuous: length of prior wakefulness has a discontinuity, dropping to zero at sleep onset; and the out-of-phase metric has a discontinuity that is an artifact of the SAFTE calculation (page 18). Hours of sleep in the last 24 hours approaches a limit at about 12 to 14 hours per day. Cumulative sleep debt oscillates across days of sleep restriction. In some cases, there would be disproportionate numbers of zeros, compared to other values. This would disturb rectangular and chi-square distributions. We would need to limit our sampling to non-sleep periods. Finally, we concluded that the use of continuous variables would be problematic.

USING PERFORMANCE EFFECTIVENESS AND FATIGUE INDICATORS TO ESTABLISH A FATIGUE ORM MEASURE

In the standard ORM method (AFPAM 90-902, 14 Dec 2000), the risk of a mishap is measured in terms of the probability that a mishap will occur and the potential severity of that mishap. The standard two-way matrix of probability and severity is shown in Table 16. The severity component of the matrix must be specified by the operator. For the probability of a fatigue-related mishap, the definitions in AFPAM 90-902 (par. 24) may be adapted as follows:

- FREQUENT—Involuntary inattention/sleep will occur often during the duty period
- LIKELY—Involuntary inattention/sleep will occur several times during the duty period.
- OCCASIONAL—Involuntary inattention/sleep will occur once during the duty period.
- SELDOM—Involuntary inattention/sleep may occur once during the duty period.
- UNLIKELY—Involuntary inattention/sleep is so unlikely that you may assume it will not occur during the duty period.

Table 16. Standard ORM Matrix for an Event (Reproduced from AFPAM 90-902).

	Probability of Mishap				
Severity of Mishap	*Frequent*	*Likely*	*Occasional*	*Seldom*	*Unlikely*
Catastrophic	EXT HIGH	EXT HIGH	HIGH	HIGH	MEDIUM
Critical	EXT HIGH	HIGH	HIGH	MEDIUM	LOW
Moderate	HIGH	MEDIUM	MEDIUM	LOW	LOW
Negligible	MEDIUM	LOW	LOW	LOW	LOW
	Risk Levels				

Note that a fatigue-related mishap is a joint probability event. A brief period of fatigue-induced inattention or involuntary sleep must coincide with the occurrence of a critical signal in the operational environment. For example, if an important piece of information is presented only briefly in a weapon system display, due perhaps to the physical nature of the system sensors, the alert, well-trained operator is likely to detect its presence and respond appropriately. However, if the brief display period coincides with a period of involuntary inattention or sleep, the piece of information will not be detected. This detection failure may have a wide range of severity in terms of its effects on the weapon system or the environment or people that the system was designed to protect.

In making a fatigue ORM recommendation, one would like to have the most powerful possible predictor of the probability that a mishap will occur due to fatigue. We have shown that the expert knowledge provided by SAFTE's predicted cognitive PE and the five fatigue indicators could be combined to give such a prediction.

DISCUSSION

In considering the use of the FAST™ indicators in addition to the PE measure for fatigue ORM determination, the following three questions were posed. First, in what manner and frequency did the indicators appear in schedules? Second, how did the indicators correlate with percent cognitive PE? Third, did the indicators offer any additional fatigue information not captured in the PE measure? The analysis of the five scenario schedules presented above indicates that the dynamic range of the indicators should be restricted to four since in no schedule were five indicators present at the same time. Further, although the indicators may contribute to a fatigue prediction, not all of them are independent of the PE measure as shown by the factor analysis. Less than eight hours of sleep in the last 24 hours (< 8), cumulative sleep debt of more than eight hours (> 8), and more than 17 hours of continuous wakefulness (> 17) load on the same factor as PE. However, awake during predawn hours (Pre) and body clock out of phase (> 3) appear to be independent of the four variables of the first factor as shown by the orthogonal relationship shown in the component plot of Figure 6.

The presence of two independent Factors as determinants of fatigue prediction, shown above, supported the idea of using two variables to predict fatigue level for ORM: the first variable is PE and the second is the <u>number</u> of fatigue indicators present. Although there is overlap of the two variables when three of the indicators are present from the Sleep Reservoir factor, the contribution of the two indicators from the Circadian Disruption factor account for an additional 23.5% of the fatigue prediction variance. The two variables together accounted for 59% of the variability. Additional factors would add about 10% each filling out the remaining 41% of unaccounted variance. However, their use would dramatically complicate the interpretation of the factors, be difficult to incorporate into the fatigue level computation, and would likely add little to fatigue prediction.

RECOMMENDATION

Thus, for fatigue ORM, we recommend using a range of 0 to 4 indicators in an ORM matrix, and including a caveat in related text about the rare and extreme fatigue that would probably be present if five indicators were ever to be predicted. There should also be an explanation of the delayed onset of the out-of-phase indicator.

IMPLEMENTATION OF THE ORM FATIGUE PROBABILITY METRIC

Having decided that fatigue severity should be determined using both performance effectiveness (PE) and the number of fatigue indicators, we prepared a table with PE and number of indicators comprising the rows and columns, respectively, to guide our design efforts. We needed to provide a basis for five levels of probability (top row of Table 16, above): Frequent, Likely, Occasional, Seldom, and Unlikely.

We used expert opinion to determine the probability of a mishap. We referred to the median number of fatigue indicators when PE was in each of four intervals: PE = 90+, median = 1 factor; PE = 77 to 89, median = 2 factors; PE = 65 to 76, median = 2 factors; PE = 0 to 64, median = 4 factors. Then we assigned probability ratings from top to bottom in each column (Table 17).

Table 17. ORM decision matrix for the probability of a fatigue-induced mishap.

	Number of Fatigue indicators				
% PE	**0**	**1**	**2**	**3**	**4**
90+	Unlikely	Unlikely	Unlikely	Seldom	Occasional
77-89	Seldom	Seldom	Occasional	Occasional	Likely
65-76	Occasional	Likely	Likely	Likely	Frequent
0-64	Frequent	Frequent	Frequent	Frequent	Frequent

We used Table 17 to assign fatigue levels to the five scenarios to evaluate the reasonableness of the assignment. While the sample times used in the five scenarios were determined by indicator appearance and disappearance rather than by work events or specific intervals of time, the conditions present at the time of rating were sufficient to determine the reasonableness of the fatigue risk. Figure 7 shows the distribution of fatigue risk levels across all five scenarios.

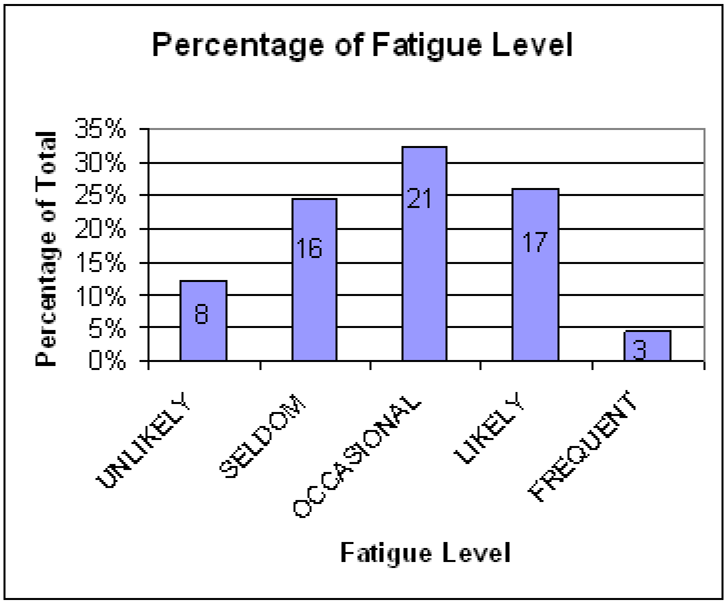

Figure 7. Percentage of each fatigue probability from the data of the five scenarios. The frequency is indicated within each column of the histogram.

Since each scenario was selected to present high levels of fatigue, it is not surprising that "Occasional" was the most frequent probability. A more typical schedule would be that of shiftwork. Figure 8 shows a breakout for the shift work schedule DDSSNNNOO. The median is the same for both distributions, but there are two modes, at "Seldom" and "Likely."

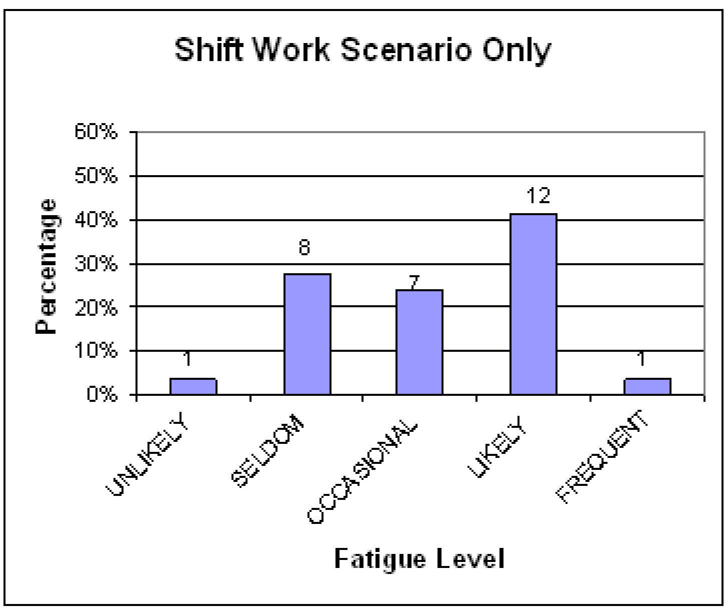

Figure 8. Percentage of each fatigue probability from the data of the shiftwork scenario. The frequency is indicated above each column of the histogram.

APPLICATION

We may now consider how we might use these fatigue probability levels for use in ORM. Air Mobility Command uses four risk levels in evaluating fatigue (Air Mobility Command Instruction 90-903, 2006). A brief example of a possible aviation schedule follows. For a specific landing, F-PAS (or FAST™) indicates a PE of 82 with two fatigue indicators (indicators). Using the results shown in Table 17, the probability of fatigue occurrence is predicted by the software to be "occasional." The scheduler or aircrew should apply the ORM matrix from Table 16 as shown in the middle column of Table 18. If the severity of mishap is judged to be "catastrophic," then the fatigue-predicted risk level would be "HIGH" (top row, third column), and the appropriate authority would have to sign off for a waiver. If the severity is judged to be "negligible," then the fatigue-predicted risk level would be "LOW" (bottom row, third column). F-PAS should print a table such as Table 18 for each event within a flight schedule. These tables should augment the ORM documents the aircrew are required to complete for each mission and mission event.

Table 18. Fatigue ORM matrix for the landing example.

	Probability of Fatigue-Induced Mishap				
Severity of Mishap	*Frequent*	*Likely*	***Occasional***	*Seldom*	*Unlikely*
Catastrophic			**HIGH**		
Critical			**HIGH**		
Moderate			**MEDIUM**		
Negligible			**LOW**		
	Risk Levels				

ANALYSIS OF FATIGUE RISK CONTROL MEASURES

Effective mitigation measures should reduce the probability of, severity of, or exposure to risk (AFI 90-901). The main cause of fatigue is lack of adequate sleep (both quantity and quality). The best fatigue countermeasure is sleep, which is the only countermeasure that provides recovery. It also reduces the probability that fatigue will have an effect on mission safety and, concomitantly, reduces the exposure of mission performance to the ill effects of fatigue. When adequate sleep cannot be used to counter fatigue, then one must consider the use of "Go" and "No-go" adjuncts. These adjuncts serve to reduce the severity of fatigue effects or the exposure to fatigue-related risk. The characteristics of each control measure are listed, below.

SLEEP

- Sleep debt should be avoided whenever possible. It is part of crews' duties to keep cognitive skills sharp through adequate sleep. Though one cannot "store" sleep, you can and should avoid the build-up of cumulative fatigue due to sleep debt. Operators and decision-makers must be sharp every day and also be ready to pull an all-nighter, when necessary. Crews should always be rested and as ready as possible to accomplish night work. The minimum recommended amount of sleep is eight hours per night (yes, eight!).

- Recovery sleep is necessary and should be allowed for and planned for when a sleep debt exists. Fortunately, we are efficient at paying back this debt. You can pay it back two to four times faster than it accumulated. Thus, eight hours of debt can be paid back with two to four hours added onto eight hours of good-quality, nocturnal sleep (a total of 8 to 12 hours).
- Implement an in-office or in-squadron napping strategy to keep crews as sharp as possible.
  - Aircrews: "…controlled cockpit rest may be implemented when the basic aircrew includes a second qualified pilot." (AFI 11-202, *General Flight Rules*, Par 9.9.6)
- Emphasize good sleep hygiene and good nutrition. Refer to the National Sleep Foundation (www.sleepfoundation.org) for up-to-date information.
- Use no caffeine during the 6 hours before planned sleep, including planned naps.
- Consume no alcohol or only within legal limits (1 drink per hour) or less. While alcohol may shorten sleep latency, it reduces sleep length and quality.

"GO" ADJUNCTS

Reschedule or Truncate the Mission or the Duty Day

- The objective of this administrative control is to avoid the pre-dawn effects of the circadian rhythm and/or the effects of prolonged wakefulness.
- Aircrews: "PICs [pilots in command] must terminate a mission or mission leg if safety may be compromised by fatigue factors..." (AFI 11-202, *General Flight Rules*, Par 9.2.3)

Reduce Mission Work Demand

- The objective here is to match work demand to the level of crew fatigue.

Bright Light

- For crews who do not need to work in darkness or dim light, bright lighting overhead may suppress normal, nocturnal melatonin secretion and concomitant sleepiness. [In all-night command and control operations, computer displays that require dim ambient light for adequate viewing should be replaced with displays that are compatible with bright ambient lighting.]
- Bright light exposures in a new time zone before and after the expected sleep period may accelerate phase delays and phase advances, respectively, of one's circadian rhythms. However, in the absence of real-time, accurate knowledge of the expected sleep period, there is a substantial risk that inappropriately timed bright light exposures will aggravate shift lag.
- <u>Given knowledge of this risk</u>, a crew may wish to refer to the calculator at the web site of Outside In, Ltd. (www.bodyclock.com). It appears that this calculator may be used safely, with three caveats.
  - First, emphasize to the crews that the times cited for light exposure are local at the new location.

- Second, emphasize that going beyond the prescription (i.e., using it for more days than prescribed on the site) is not advisable. The reason for this is that, after a couple of days of light therapy in the new time zone, you no longer know exactly the timing of your expected sleep period.
- Finally[4], emphasize to the crews that each person's response to the light exposure may vary. Thus, if it isn't working for you but it is for your friend, go with what your body is telling you, not what is happening with your friend. Your circadian rhythm may be slightly different from your friend's and therefore respond differently

- "Another way to look at the use of bright light to move the melatonin peak around is to imagine a long, skinny balloon that is inflated just in the middle and still skinny at both ends. The inflated bubble represents the melatonin peak that occurs between midnight and dawn. If you squeeze the right-hand part of the bubble, it will shift left. That's like morning light pushing the peak earlier. If you squeeze the left-hand part of the bubble, it will shift right. That's like evening light pushing the melatonin peak later."[5] What's not said clearly here is that the middle bubble is your <u>expected</u> sleep period, based upon your home sleep period and the sleep period's subsequent phase changes with respect to the new, local day-night cycle.

Caffeine

- Caffeine promotes wakefulness, enhances vigilance performance and lessens feelings of weariness.
- The half-life for caffeine metabolism is typically 5-6 hours.
- Be judicious with caffeine use. Use it sparingly so that you do not habituate to its excellent alerting effects: take it only every 3 to 4 hours and not in excessive amounts (limit to 250 mg/day or less).

Dextroamphetamine (Dexedrine®)

- Dextroamphetamine is one of the most potent central nervous system (CNS) stimulants. It has been demonstrated to increase concentration, as well as enhance physical performance in addition to modestly increasing the basal metabolic rate.
- The elimination half-life of dextroamphetamine is 12 hours. Peak blood concentrations occur at about 3 hours. Occasional side effects are rapid heart rate, elevated blood pressure, euphoria, dizziness, headache, diarrhea, and dry mouth.
- Dextroamphetamine is approved by the Air Force (AFI 48-123) for use as an alertness enhancer in both single-pilot fighter and dual-pilot bomber long-duration missions.
- Existing data indicate that 10mg doses of dextroamphetamine provide operationally relevant resistance to the effects of sleep deprivation in aviation contexts. Air Force guidance recommends 4-6 hours between successive doses of 10mg dextroamphetamine, and a limit of 60mg per 24-hour period.
- Retrospective studies on the use of dextroamphetamine in combat operations consistently report extended alertness in fatigued aircrews conducting long-duration

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4 Dr. J. Lynn Caldwell, personal communication.

5 Miller JC, *Controlling Pilot Error: Fatigue*, McGraw-Hill, 2001.

missions, with no adverse side effects or a need to continue the drug after typical work/sleep schedules were reinstated (Cornum et al., 1995[6]; Emonson and Vanderbeek, 1993; Senechal, 1988).

Modafinil (Provigil®)

- Modafinil is a member of a new class of drugs called Eugregorics. Eugregorics mimic the alerting effects of amphetamines by producing high quality wakefulness in sleep deprived subjects, while lacking the negative side effects sometimes associated with amphetamines (modafinil is a schedule IV controlled substance; dextroamphetamine is a schedule II).
- Modafinil has a terminal half-life of 9-14 hours with peak blood concentrations 2-4 hours after absorption, making it a prime candidate for operational applications (Wong et al., 1997).
- Cephalon Inc. received FDA approval in 1998 to market modafinil for the management of excessive daytime sleepiness associated with narcolepsy, and very recently for treatment of shift-worker sleep deficit.
- Modafinil was approved for use in some AF operations by ACC/SG. Initially, the normal dose for AF operational use is 200mg orally every eight hours as needed, not to exceed 400mg in 24 consecutive hours. Preliminary reports from the field have suggested that for 24-hour and longer periods requiring continuous wakefulness, 600mg per 24 hours should be considered as an option.
- It has been consistently demonstrated in several studies that 100mg, 200mg and 300mg of modafinil administered either in single doses or, in split doses at four- or eight-hour intervals for longer periods of arousal, significantly enhances cognitive performance during extended periods of sleep deprivation (Bensimon et al., 1991; Lagarde and Batejat, 1995; Batéjat and Lagarde, 1999; Baranski et al., 1998; Stivalet et al., 1998).
- Unlike amphetamines, 100-300mg/day modafinil produces a long lasting waking effect without concern for behavioral modification, addictive attributes, adverse symptoms, or sleep rebound effects (Lagarde et al., 1995; Lin et al., 1997; Morehouse et al., 1997; Warot et al., 1993).
- Doses of 400-800mg/day have sometimes generated reports of headache, elevated pulse rate and blood pressure, dizziness, and sleep rebound (Caldwell et al., 2000; Batéjat and Lagade, 1999; Lagarde and Batejat, 1995; Buguet et al., 1995).
- Doses of 200mg and 400mg of modafinil attenuated fatigue effects on cognitive performance without producing overconfidence or negative vestibular effects (Eddy, Gibbons, Miller, et al., 2005; Eddy, Gibbons, and Stevens, 2005).

"NO-GO" ADJUNCTS

Declare Additional Crew Rest

- The objective of this administrative control measure is to allow needed sleep to be acquired.

[6] The full citations for the research papers cited in the Control Measures section of the TM are available from the authors.

- Aircrews: "The PIC [pilot in command] may recommend restricting duty time or extending crew rest periods to the MAJCOM approval authority. PICs must terminate a mission or mission leg if safety may be compromised by fatigue factors…" (AFI 11-202, *General Flight Rules*, Par 9.2.3)

Temazepam (Restoril®)

- Temazepam, a benzodiazepine compound, is approved by the FDA for short-term treatment of insomnia, providing symptomatic relief of difficulty in falling asleep, frequent nocturnal awakenings, and early morning awakenings.
- It has an elimination half-life of 8 hours and peak blood concentration at 1.5 hours. Although infrequent, the most common side effects are dizziness, drowsiness, nausea, and diarrhea.
- Temazepam is approved by the Air Force (AFI 48-123 and ACC/SG policy letter 27 Sep 1999; Appendix M) for use by aircrew as a sleep aid during pre-mission crew rest. The Air Force directs that a dose not to exceed 30 mg temazepam be taken a minimum of 12 hours prior to reporting for duty to assure clearance and absence of hangover effects. The operational use of temazepam is restricted to a maximum of 7 consecutive days and no more than 20 days in a 60-day period.

Zolpidem (Ambien®)

- Zolpidem is a strong sedative with minor anxiolytic, myorelaxant, and anticonvulsant properties, and has been shown to be effective in inducing and maintaining sleep in adults with various sleep pathologies. Zolpidem is approved by the Food and Drug Administration (FDA) for short-term treatment of insomnia. Studies document that zolpidem produces no rebound or withdrawal effects and study subjects have experienced good daytime alertness after 20mg doses given at night.
- Peak plasma concentrations are reached 0.5 to 1.0 hours after ingestion. The elimination half-life averages about 2.5 hours. Although infrequent, the most common side effects of zolpidem are dizziness, drowsiness, nausea, and diarrhea.
- Zolpidem is approved by the Air Force (AFI 48-123 and ACC/SG policy letter 27 Sep 1999; Appendix M) for use by aircrew as a sleep aid during pre-mission crew rest. The Air Force directs that 10mg zolpidem be taken at a minimum of six hours prior to reporting for duty to assure clearance and no hangover effects. Operational use of zolpidem is restricted to a maximum of 7 consecutive days and no more than 20 days in a 60-day period.

Zaleplon (Sonata®)

- Zaleplon is a short-duration sleep aid, similar in mode of action to zolpidem but shorter acting, with sleep onset occurring within 30-minutes of oral ingestion of a 10-mg tablet.
- The most common side effects include: headache, dizziness and somnolence. Outside of somnolence, in short-term clinical studies (Elie, Ruther, Farr, Emilien, & Salinas, 1999), the side effects for zaleplon are not significantly different from placebo. There is no evidence of rebound insomnia or withdrawal symptoms following discontinuation of the medication (10-mg dose).
- Zaleplon is approved by the Air Force (AFMOA/CC policy letter 4 June 2001) for ground-based use by air crew and special duty personnel as a sleep aid. The use of

zaleplon is restricted to a maximum of 10 consecutive days and no more than 28 days in a 60 day period.

Melatonin

- The naturally occurring hormone melatonin has received widespread public support as a safe and non-prescriptive means to induce sleepiness with typical doses of 3-10 mg. It has the distinct military advantage of not promoting sleep by CNS depression that would preclude personnel from going on duty before drug washout.
- The mean peak blood level for ingested melatonin occurs about an hour after ingestion and the elimination half-life is about 2-3 hours across a wide variety of doses.
- Melatonin is primarily synthesized and secreted by the pineal gland but also produced in other tissues such as the retina.
- Melatonin is not currently approved for aircrew use in the United States Air Force[7].

POSSIBLE FATIGUE RISK CONTROL DECISIONS

"Decisions are made at the appropriate level and are based upon analyses of overall costs and benefits. Decision-makers choose the most mission supportive risk controls consistent with ORM principles." Primarily, decision-makers should "accept no unnecessary risk," but "accept risk when benefits outweigh the costs." (AFI 90-901). Napoleon espoused the first of these two principles.

In the discussion of risk control decisions the following ORM levels should be kept in mind. Level 1 is low risk, level 2 is medium risk, level 3 is high risk, and level 4 is extremely high risk.

To make a case for the second principle, one should probably avoid the conduct of safety-sensitive jobs when fatigue risk levels exceed three. This recommendation is made for two reasons. First, basic arithmetic: if the risk is "critical" (level 1), then it is difficult to imagine a situation in which benefit outweighs the potential cost.

Second, accuracy: the quantification of subjective estimates is not an exact science. One crew's risk level estimate of 2 may be a 1 for another crew and a 3 for still another crew. This lack of accuracy begs the allowance of a comfortable margin of error.

After controls have been selected to eliminate hazards or reduce their risk, one must determine the level of residual risk. "Residual risk is the risk remaining after controls have been identified, selected, and implemented for the threat. As controls for threats are identified and selected, the threats are reassessed, and the level of risk is revised. This process is repeated until the level of residual risk is acceptable to the commander or leader or cannot be further reduced." (AFTTP(I) 3-2.34, *Risk Management*, February 2001)

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[7] Air Force Surgeon General (22 Sep 2004). *Official Air Force Approved Aircrew Medications Quick Reference List*. AF/SGOP, Bolling AFB, DC.

SLEEP

Good quality, nocturnal sleep is a particularly effective control for the three hazards, Length of prior wakefulness, Amount of prior sleep, and Physical exertion. One method that can be used to calculate the amount of sleep needed for effective risk control is to estimate sleep debt and the amount of sleep needed to repay the debt. Sleep debt is the difference between an individual's desired, ideal sleep length and their actual sleep length, and it accrues from day to day. It is repaid at a rate of 1 to 2 hours of good-quality nocturnal sleep for every four hours of debt.

All controls except sleep should be viewed as "band-aid" approaches, to be used as a last resort when other controls are insufficient and the mission must be accomplished. Recovery sleep will still be necessary after the other controls have been applied to accomplish the mission.

RESCHEDULE OR TRUNCATE THE MISSION OR THE DUTY DAY

This approach is effective for the two hazards, Time of day and Time zone change and days in zone. The objectives are to (1) prevent safety-sensitive work from occurring at the nadir of a crew's body clock and (2) schedule the work when the crew's predicted cognitive PE is at or above 90%.

REDUCE MISSION WORK DEMAND

This approach is effective for all fatigue hazards, especially if work demand can be reduced from safety-sensitive to non-safety-sensitive.

BRIGHT LIGHT

This approach may be effective for the hazards, Time of day, Number of night shifts, and Time zone change. It has been reported that bright light, used properly with respect to the expected sleep period (not a straightforward task), may accelerate acclimation to a new time zone by a factor of three. The <u>non</u>-bright-light rules of thumb for acclimation are 1 hour per day for westward travel and 40 minutes per day for eastward travel.

CAFFEINE, DEXTROAMPHETAMINE, AND MODAFINIL

These adjuncts are quite effective for all fatigue hazards. They may fully counter the effects of fatigue on cognitive performance effectiveness for limited periods.

DECLARE ADDITIONAL CREW REST

The objective here is to acquire more sleep. Thus, this control is effective for the three hazards, Length of prior wakefulness, Amount of prior sleep, and Physical exertion.

TEMAZEPAM, ZOLPIDEM, ZALEPLON AND MELATONIN

These adjuncts induce sleep. Thus, they are effective for the three hazards, Length of prior wakefulness, Amount of prior sleep, and Physical exertion. In addition, they may be used effectively to phase advance sleep before and during eastward travel across time zones. Their relative effectiveness levels for inducing and sustaining sleep are temazepam > zolpidem > zaleplon > melatonin. There are large individual differences in effectiveness across the three drugs (melatonin is a hormone). All personnel should ground test all three drugs with medical supervision.

QUANTITATIVE PREDICTIONS

The human system is subject to biological changes and rhythms that introduce predictable variability. Quantitative models, implemented in software, can predict the timing and severity of fatigue episodes, given some well-substantiated assumptions about when and how much people will sleep on any given work-rest schedule. The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model integrates quantitative information about (1) circadian rhythms in metabolic rate, (2) cognitive performance recovery rates associated with sleep, (3) cognitive performance decay rates associated with wakefulness, and (4) cognitive performance effects associated with sleep inertia to produce a 3-process applied model of human cognitive performance effectiveness. This model, implemented as the Windows® software, *FAST*™, or the web-based software, F-PAS, may be used as an objective predictor of fatigue levels throughout a variety of sustained operations. The predictions can guide operators toward specific risk control options.

Having determined the level of residual risk, there are four possible paths to follow:

- Accept the plan as is: the benefits outweigh risks (costs), and residual risk is low enough to justify the proposed action. The decision maker must then allocate resources to control risk.
- Reject the plan out-of-hand: the risk is too high to justify the operation in any form.
- Modify the plan to develop measures to control risk: the plan is valid, but the current controls do not minimize risk adequately. Further work to control the risk is necessary before proceeding.
- Elevate the decision to higher authority: the risk is too great for the decision-maker's level of authority and all possible controls have been considered.

IMPLEMENTATION OF FATIGUE RISK CONTROLS

"Once the risk control decision is made, assets must be made available to implement specific controls. Part of implementing control measures is informing the personnel in the system of the risk management process results and subsequent decisions. Careful documentation of each step in the risk management process facilitates risk communication and the rational processes behind risk management decisions." (AFTTP(I) 3-2.34)

MAKE IMPLEMENTATION CLEAR

Presently, the *FAST*™ software allows decision-makers and schedulers to cut and paste graphs and tables into digital documents for word processing and slide shows. Additionally, it has a specialty function that prints a mission timeline allowing the development of a cockpit napping plan for extended (24 hours and longer) bomber missions.

ESTABLISH ACCOUNTABILITY

Good sleep hygiene requires that management provide good sleeping quarters and that personnel use the quarters and practice good pre-sleep behaviors. More specifically, it means that management must provide a quiet, cool, dark, comfortable sleeping space and protect and maintain it; and that each individual must sleep during the rest period, avoid sleep disturbing practices and not ingest sleep disturbing compounds (e.g., alcohol, caffeine, nicotine) before sleep.

The use of prescription and non-prescription pharmacological adjuncts requires the medical support of the local SG. Also, the AF/SG has identified Flight Surgeons and Aerospace Physiologists as members of Human Performance Training Teams (HPTT). Where an HPTT is available, its members can help operators deal with fatigue risk management.

In addition, Biobehavioral Performance Branch (AFRL/HEPF) at Brooks City-Base, TX, 78235-5104, has produced Technical Reports for the benefit of crew schedulers. The first three are dedicated to aircrews and the last to shiftworkers:

- *Scheduling Aircrews 1: Intra-Theater 24/7 Operations*. Technical Report AFRL-HE-BR-TR-2005-0074, Air Force Research Laboratory, Brooks City-Base TX, May 2005. (ADA434696)
- *Scheduling Aircrews 2: Nighttime Missions*. Technical Report AFRL-HE-BR-TR-2005-0075, Air Force Research Laboratory, Brooks City-Base TX, May 2005. (ADA435393)
- *Scheduling Aircrews 3: Deployment*. Technical Report AFRL-HE-BR-TR-2005-0047, Air Force Research Laboratory, Brooks City-Base TX, May 2005.
- *Fundamentals of Shiftwork Scheduling*. Technical Report AFRL-HE-BR-TR-2006-0011. Air Force Research Laboratory, Brooks City-Base, TX, April 2006. (ADA446688)

PROVIDE SUPPORT

The command must (AFTTP(I) 3-2.34):

- Provide the personnel and resources necessary to implement the control measures.
- Design for sustainability.
- Employ each control with a feedback mechanism that will provide information on whether the control is achieving the intended purpose.

SUPERVISION AND REVIEW

"There are three aspects: monitoring the effectiveness of risk controls; determining the need for further assessment of either all, or a portion of, the operation due to an unanticipated change; and capturing lessons learned, both positive and negative." (AFTTP(I) 3-2.34) The implementation of these functions is left to those using this Technical report to help them practice fatigue ORM. **CAUTION:** Supervision and review should **not** be accomplished by fatigued supervisors. One of the characteristics of fatigue is the willingness to accept more risk than normal.

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APPENDIX A

FATIGUE BASICS

In any human-machine system, the most variable (unpredictable) component in the system is the human. After training and currency, the greatest contributor to that variability is fatigue.

Good human-machine system design exploits human strengths and protects the system from human weaknesses. This is a fundamental concept in human factors engineering. The human brings to a system much more powerful pattern recognition capabilities and decision-making skills than can be provided in software. However, the human also brings much more performance variability to a system than one finds in software and modern hardware.

Training and currency are sources of human variability. When novices are learning to operate a complex system, they display a learning curve. Initially, their performance is quite poor and variable, but they learn the basics quickly. Next, their performance is better, on average, but still more variable than desired. Finally, as they approach the expert user level, their average performance is quite good and it varies only a small amount between excellent and good. Similarly, when an expert user becomes "rusty" in the operation of a complex system, their performance may be more variable than desired until after a few iterations.

One of the primary hallmarks of human fatigue is performance variability. This is due to large amplitude, moment-to-moment fluctuations in attentiveness associated with fatigue. Average performance may be acceptable, but there are brief periods when responses are extraordinarily delayed or absent ("lapses"). We often call this "distractibility."

We sort the generators of fatigue into the four categories circadian[8], acute, cumulative, and chronic. There are inherent, unavoidable, 24-hour rhythms in human cognitive and physical performance. Most of these <u>circadian rhythms</u> oscillate between their high point late in the day to their low point in the pre-dawn hours. <u>Acute fatigue</u> builds up unavoidably within in one waking and duty period, but recovery from acute fatigue occurs as the result of one good-quality, nocturnal sleep period. <u>Cumulative fatigue</u> builds up across major waking and duty periods because there is inadequate recovery (due to inadequate sleep) between the duty periods, and recovery from cumulative fatigue cannot be accomplished in one good-quality, nocturnal sleep period.

<u>Chronic fatigue</u> may set in after one to two weeks of cumulative fatigue. Its symptoms[9] are similar to those of Chronic Fatigue Syndrome (CFS). However, unlike CFS, the cause is known (continuing cumulative fatigue) and it occurs much sooner than the 6-month diagnostic requirement for CFS. Chronic fatigue was once called "motivational exhaustion." While this label accounts for only one of several possible symptoms (apathy), it describes well the attitude that one observes in a person with chronic fatigue.

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8 From the Latin *circa*, about, and *dia*, day: A cycle length of about one day.

9 The desire to sleep, apathy, substantial impairment in short-term memory or concentration; muscle pain; multi-joint pain without swelling or redness; headaches of a new type, pattern or severity; unrefreshing sleep; and post-exertion malaise lasting more than 24 hours.

Fatigue is ubiquitous, pervasive and insidious. By ubiquitous we mean that fatigue affects everybody. There are individual differences: a few people are truly more resistant to fatigue effects than others. Many people think mistakenly that they are more resistant to fatigue effects than others.

By pervasive, we mean that fatigue affects everything we do, physically and cognitively. Again, there are individual differences. In the physical domain, there are those who are inherently able to train too much greater levels of strength and endurance than the rest of us.

By insidious, we mean that often when we are fatigued, we are quite unaware of how badly we are performing. Most people have experienced the cognitive lapse associated with mild fatigue when they miss a freeway exit or realize suddenly that they don't remember the last mile or two driven on the highway.

Fortunately, the biological changes and rhythms that cause fatigue-induced variability in human performance are relatively lawful and predictable. We have quantitative models, implemented in software, that allow us to estimate and predict the timing and severity of fatigue episodes, given some information about when and how much people sleep. The quantitative approach is applied here to provide insight into the effects of night work on worker cognition[10].

There is no escape from fatigue. For day workers, acute fatigue begins to build at their awakening in the morning, whether or not they go to work. By late evening, they recognize the need to go to bed and get some sleep. In fact, their cognitive performance at this point is somewhat similar to the performance a person with a 0.05% blood alcohol content. For night workers, it is uncommon to acclimate fully to sleeping during the day. Thus, they sleep poorly and cumulative fatigue builds up from work shift to work shift. Most often, night workers are more fatigued at work than day workers.

[10] In this case, the ability to perform such functions as logical reasoning and mental arithmetic.

APPENDIX B

GLOSSARY

1. ***Individual differences.*** Some of the problems caused by individual differences include (a) the inability to predict, within a group of personnel experiencing the same night work or extended or irregular schedule just who will be most susceptible to fatigue and who will not; and (b) scheduling around peoples' different physiological sleep needs (generally, 6 to 9 hours) and schedules (owls and larks). For example, during surge or night operations, a supervisor may expect that someone in his/her team may fall asleep on the job. However, the supervisor cannot predict who or exactly when and thus is at a disadvantage for managing this risk. Additionally, (c) medical ground testing of any pharmaceutical countermeasure to fatigue should characterize each individual's reaction, and serve to prevent the occurrence of dangerous reactions during the performance of safety-sensitive jobs.

2a. ***Working memory***. The focal point for human information processing. The scratch pad upon which you make mental comparisons and integrate new information with old information. Important for command and control teams and for aircrews, and affected strongly by moderate fatigue. For example, working memory impairment may cause an inability to remember radio frequencies or other information during the few minutes after receiving the information.

2b. ***Anterograde amnesia.*** The inability to remember needed, new information after it is presented. Especially critical for command and control teams and for the pilot's crosscheck. For example, an inability to recall flight parameters briefed before take-off.

2c. ***Retrograde amnesia***. The inability to remember needed, old information. This is why we use hard-copy and computerized reference sources.

2d. ***Cognitive impairment.*** Includes decrements in response time and/or accuracy in tasks such as logical reasoning and relatively simple mental arithmetic. Also includes impaired decision making. Especially important for command and control teams and for aircrews. *Cognitive functions, basic.* The functions required to perform more complex, integrative cognitive tasks; infrastructure. *Cognitive functions, complex.* Complex, integrative functions.

2e. ***Slowed response time (RT) and reduced response accuracy***. Includes decrements in response time and accuracy in tasks such as simple reaction time tasks through choice reaction time tasks to logical reasoning and mental arithmetic. Especially important for aircrews and affected strongly by moderate fatigue. For example, hesitation in identifying a problem or a target and/or not taking definitive or appropriate action.

2f. ***Manual control***. For example, steering a car or flying with stick and rudder. When these tasks are learned to the point of automatic behavior, as they are in licensed drivers (most of them, anyway) and professional pilots, they are quite resistant to fatigue. Important for pilots and drivers.

2g. ***Vigilance.*** The human brain does a poor job, normally, of remaining alert in a boring situation, waiting for an important but rare occurrence. Even mild fatigue makes the situation worse. Especially important for security guards, aircrews dependent upon autopilots, personnel monitoring satellite warning systems, etc.

2h. ***Narrowed attention***. Fatigue causes us to shed tasks, decreasing the number of things that we try to pay attention to. Similar to the tired or distracted pilot's "channelized attention" (an undue focus on one parameter of flight to the exclusion of other essential parameters). Important for both command and control teams and for aircrews.

2i. ***Hypnagogic hallucinations***. Dreams that occur during wakefulness, especially during the pre-dawn hours. A not-uncommon symptom of moderate to severe cumulative fatigue.

3a. ***Willingness to accept greater risk***. Limited research suggests that alcohol causes you to be more willing to take a risk even though your ability to estimate risk remains fairly accurate. For example, you may opt to not follow standard procedures or you may perform activities with greater risk than you usually accept. Fatigue appears to have the same effect (not supported by research; under investigation). Important for pilots, command and control teams and drivers.

3b. ***Loss of situation awareness.*** "Continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events." (C Dominguez, 1995). Depends upon working memory, and is impaired by both retrograde and anterograde amnesia. Especially important for command and control teams and aircrews.

4. ***Mood impairment***. The emotional state generated by the interaction of the individual with the physical and human environments. For example, impaired mood may be characterized by depression, lack of motivation and/or reluctance to participate or communicate with others. Important for command and control teams and for aircrew resource management (CRM). *Motivation.* "An internal process that pushes or pulls the individual, and the push or pull relates to some external event." Involves drive, desire and goal orientation. (ED Ferguson, 2000).

5a. ***General malaise***. The overall, undesirable feeling caused by illness and by cumulative fatigue and jet lag. Includes physical, cognitive and emotional components.

5b. ***Aerobic capacity***. Your maximum capacity to perform endurance-requiring physical activities. The normal circadian rhythm in metabolic function reduces aerobic capacity about 10% during the pre-dawn hours, compared to mid-day. Cumulative fatigue may have a similar effect.

5c. ***Drowsiness.*** The state of diminished responsiveness between relaxed wakefulness and sleep. Subtle changes in the environment may not be perceived. For example, a drowsy driver may not perceive a slow drift off the side of the road.

5d. ***Sleep debt, recovery sleep.*** Eventually, missed sleep must be made up. That is, you must repay the sleep debt that you incur. Fortunately, the payback requirement is less than the debt (such a deal!) at a ratio of about 2.5 to 1. For example, if you need 8 hours of sleep at night and get only 5, you carry a sleep debt of 3 hours forward to the next night. In the absence of an environmental or circadian disturbance or a requirement to get out of bed, you will probably sleep for your regular 8 hours plus another (3 / 2.5 =) 1.2 hours.

5e. ***Falling asleep on the job.*** The state of diminished responsiveness beyond drowsiness, especially frank episodes of sleep lasting from a few seconds to several minutes. Obvious changes in the environment and the occurrence of the sleep episode may not be perceived by the individual.

5f. ***Dizziness.*** The subjective condition of faintness, vertigo, gait disturbance, or abnormal head sensation; the latter two symptoms are the more likely to occur as a result of fatigue. Important for aircrews.

5g. ***Decreased altitude tolerance.*** Cumulative fatigue may reduce the responsiveness of the physiological acclimatization mechanisms needed to operate at moderate and high altitudes. Not supported by research; under investigation.

5h. ***Decreased thermal tolerance.*** Cumulative fatigue may reduce the responsiveness of the physiological acclimatization mechanisms needed to operate in high ambient temperatures. Not supported by research; under investigation.

5i. ***Decreased acceleration tolerance***. Cumulative fatigue may reduce the strength and endurance needed by a fighter/attack crew to sustain high acceleration (not supported by research; under investigation).

5j. ***Cardiovascular health effects.*** Especially, chronically elevated blood pressure. Known to occur in long-term shiftworkers.

5k. ***Gastrointestinal health effects.*** Especially, indigestion and ulcers. Known to occur in night- and shiftworkers.

6a. ***Worsening of alcohol effects.*** Both alcohol and cumulative fatigue appear to have similar and somewhat additive effects on response time (slower and more variable), response accuracy (less accurate and more variable), and manual control (slower and more variable). Both may also encourage the acceptance of greater levels of risk. Alcohol can add to drowsiness and cause more rapid than normal sleep onset. However, it then impairs subsequent sleep, reducing potential recovery.

6b. ***Modulation of drug effects.*** There is an interdependence between human circadian rhythms and the risk factors, pharmacologic sensitivity, and pharmacokinetics of many drugs.

7a. ***Reduced interpersonal communications.*** Fatigue causes us to shed tasks, decreasing the number of things that we try to pay attention to. One of the first things to go is communications. Important for command and control teams and for aircrew resource management (CRM).

7b. ***Loss of shared situation awareness.*** "Continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events." (C Dominguez, 1995). Depends upon working memory, and is impaired by both retrograde and anterograde amnesia. In crew or team situations, failures to share critical flight information or to point out mistakes may lead to reduced shared situation awareness. Especially important for command and control teams and aircrews.

Added Drug Hazards

Hangover. Undesirable drug effects that linger well after the period of desired effect. For example, some older sleep aids caused anterograde amnesia that extended well beyond the period of sleep that they helped provide. The best-known hangover effect is that of alcohol. Even after alcohol has been eliminated from the body, there may be undesired effects on cognitive performance and mood, some of which may be related to sleep disruption and others to the remaining presence of the breakdown products of alcohol.

Rebound insomnia. An insomnia that may occur when one stops the use of a sleep aid.

Withdrawal. Undesirable drug effects that linger well after repeated use has stopped. For example, rebound insomnia is usually one characteristic of withdrawal from the repeated use of some sleep aids.